TeV gamma-ray Observations of the Supernova Remnant RCW86 with the CANGAROO-II telescope

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Abstract

The supernova remnant RCW86 (G315.4-2.3) has been observed with the CANGAROO-II 10 m telescope from Woomera, South Australia. ASCA detected non-thermal X-ray emission from the south-west shell of RCW86, which is brighter than that from SN1006. The multiwavelength spectrum of RCW86 derived from radio and X-ray data indicates that the emission is due to the synchrotron radiation, and it is argued that high energy electrons emitting the detected synchrotron radiation are expected to be accelerated up to 20 TeV. Therefore, the radiation due to inverse Compton scattering with the photons of the 2.7 K cosmic microwave background is also expected to be detectable with the CANGAROO-II telescope if the magnetic field is as weak as that of SN1006. We observed RCW86 in 2001 and 2002 for a total observation time of 79 hours for ON-source data. The detection energy threshold was estimated from Monte Carlo simulations to be around 1 TeV.

1. Introduction

The origin and acceleration mechanism of cosmic rays have been long-standing problems since the discovery of cosmic rays in 1911 (Hess 1911, 1912). The shock front of supernova remnants is believed to be the most promising candidate for the acceleration of cosmic rays up to 10^{15} eV. No other class of galactic object appears to have enough energy to realize the observed flux of cosmic rays.

We, CANGAROO group, have already detected TeV gamma-rays from two SNRs, SN1006 (Tanimori et al. 1998, 2001; Hara et al. 2001) and RX J1713.7−3946 (Muraishi et al. 2000; Enomoto et al. 2002), with the CANGAROO-II 10m telescope (Mori et al. 2000).

Strong non-thermal X-ray emission was detected from SN1006 by ASCA (Koyama et al. 1995) and ROSAT (Willingale et al. 1996), and from RX J1713.7−3946

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by ASCA (Koyama et al. 1997). However, our results indicate that these two SNRs appear to have different mechanisms for TeV gamma-ray emission. TeV gamma-rays from SN1006 are explained by the synchrotron–inverse-Compton model, while it seems impossible to explain the TeV emission from RX J1713.7−3946 by the same model. The π^0 decay model seems to provide the only reasonable fit to the data (Enomoto et al. 2002). The fact that RX J1713.7−3946 is located in a dense region (Slane et al. 1999) supports this model. Clearly, it is important to study other SNRs to see whether they are also acceleration sites of cosmic rays, and, if so, which mechanism dominates the TeV emission. We have therefore selected another SNR emitting synchrotron X-rays, RCW86 (Bamba et al. 2000; Borkowski et al. 2001), for observations with the CANGAROO-II telescope.

RCW86, a type II (Clark, Stephenson 1977) and shell-like SNR, has been observed in the radio and X-ray bands with the results suggesting that accelerated high energy electrons are emitting synchrotron radiation at these energies. If the X-ray emission is due to the synchrotron mechanism, there must be the emission of TeV gamma-rays by inverse Compton scattering. This emission should be at detectable levels if the strength of the magnetic field is less than $15\,\mu$G, as shown in Fig. 1.. The galactic latitude of RCW86 is lower than that of SN1006 and higher than that of RX J1713.7−3946. RCW86 is located in a region of intermediate density between those of the two previously studied SNRs. Nearby molecular clouds have been observed by radio observations.

The detection of gamma-rays from RCW86 would be very significant for the confirmation of cosmic ray acceleration at the shock fronts of SNRs.

2. Observation and analysis

RCW86 was observed in 2001 (March, April and May) and 2002 (March and April). The tracking point of these observation was (R.A., Dec.)=(220.192°, −62.677°), where the strongest non-thermal X-ray emission was observed by ASCA. Total observation times were 79 hours and 72 hours for ON- and OFF-source runs, respectively. First, we selected the data taken under good sky conditions, and corrected the dead time of data acquisition system. The selected times after these processes are shown in Table 1. The data includes night sky background (NSB) photons and electronic noise, which deform the gamma-ray shower image. These effects were eliminated as follows; we required pixels to have more than $\sim$5 photoelectrons, be triggered within 35 nanoseconds from the center of the arrival timing distribution, and have at least 4 adjacent triggered pixels. The selected data includes any gamma-ray events, but also the huge cosmic ray background. In order to discriminate between gamma-ray–like and cosmic-ray–like events, we adopted the standard "Imaging Technique" (Hillas 1985; Weeks 1989). In this analysis, conventional image parameters of "Distance", "Length", "Width" and "Alpha" were used.

The two years data have been analysed separately. Furthermore, the data was divided into three parts by energy: below 1 TeV, 1 to 2 TeV, and above 2 TeV). The imaging cuts were decided in each region considering the energy dependence of the shower image based on the result of Monte Carlo simulations.

3. Energy threshold

Monte Carlo simulations of the gamma-ray spectrum of RCW86 were carried out using GEANT 3.21 (CERN 1994) considering atmospheric and detector conditions. Gamma-ray showers were simulated for a zenith angle of 35°, in the energy range from 150 GeV to 15 TeV, and with an initial power index of -2.5. The same cuts as for the real data were applied. Figure 2. shows the effective detection area and the simulated spectrum for gamma-rays for RCW86. From this figure, the detection energy threshold was estimated to be around 1 TeV, which is defined as the modal value of the broad peak of this spectrum. This detection energy threshold is higher than other results of the CANGAROO-II telescope. This arises from the lower declination of RCW86, and the higher ADC threshold required to reduce the effects of background light from the township of Woomera.

4. Results and discussion

The preliminary distribution of the orientation angle "Alpha" is shown in Figure 3. The two years data are plotted separately, in energy bands below the threshold energy ($<\sim$ 1 TeV) and above it ($>\sim$ 1 TeV), respectively. In the region of "Alpha" $> 30°$, the number of OFF-source events is normalized to that of ON source events, and the significance of the excess events is calculated for "Alpha" $<$ 15 degree.

In both years, a $\sim 4\sigma$ excess was observed in the upper energy region.

Peaks are seen at low values of alpha above 1 TeV in 2001 and 2002, while there is no significant peak below 1 TeV, as shown in Fig. 3.. This may arise if the TeV gamma-rays are due to inverse Compton scattering by high energy electrons, as in the case of SN1006. However, it is premature to claim that this SNR is emitting TeV gamma-rays: further analysis of this data is being undertaken.

Table 1. Observation time of RCW86.

	observed		selected	
	ON	OFF	ON	OFF
2001	38h 09m	33h 59m	28h 12m	23h 05m
2002	41h 11m	38h 37m	30h 08m	33h 49m

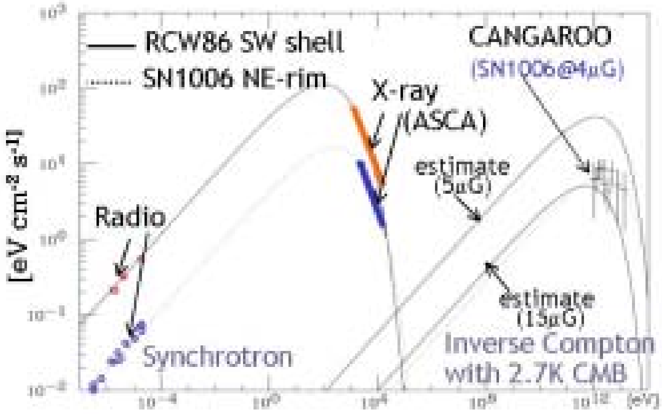

Fig. 1. Multiwavelength spectra of RCW86 (solid line) and SN1006 (dashed line). Synchrotron model is applied to real observation data for the lower energy band, and as its counterpart, inverse Compton model is for the higher energy band. The strength of magnetic field is assumed to be 5μG and 15μG for spectrum of RCW86. The lines of SN1006 are both based on real data. The fitting line for CANGAROO result was culculated by Naito (1999).

5. Conclusion

RCW86 has been observed with the CANGAROO-II 10 m telescope for 58 hours (ON-source data after cuts). The standard imaging cuts have been applied. At present, the “Alpha” distributions of the higher energy data contain excesses, but additional work is required to decide whether it is due to gamma-ray emission. In the energy region above the energy threshold, the detected gamma-ray-like signal exceeds 4.6σ and 3.7σ in 2001 and 2002, respectively. It implies the possibility of gamma-ray emission derived from inverse Compton scattering in the SW shell of RCW86 from high energy electrons. However, this result is very preliminary and further analysis of this possible TeV candidate is required.

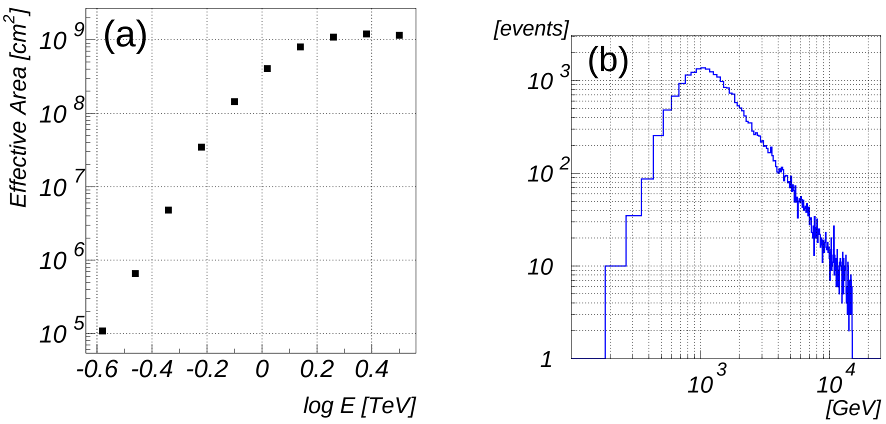

Fig. 2. Effective detection area (a) and its product with $E^{-2.5}$ spectrum (b). The energy threshold is preliminarily estimated to be around 1 TeV.

6. References

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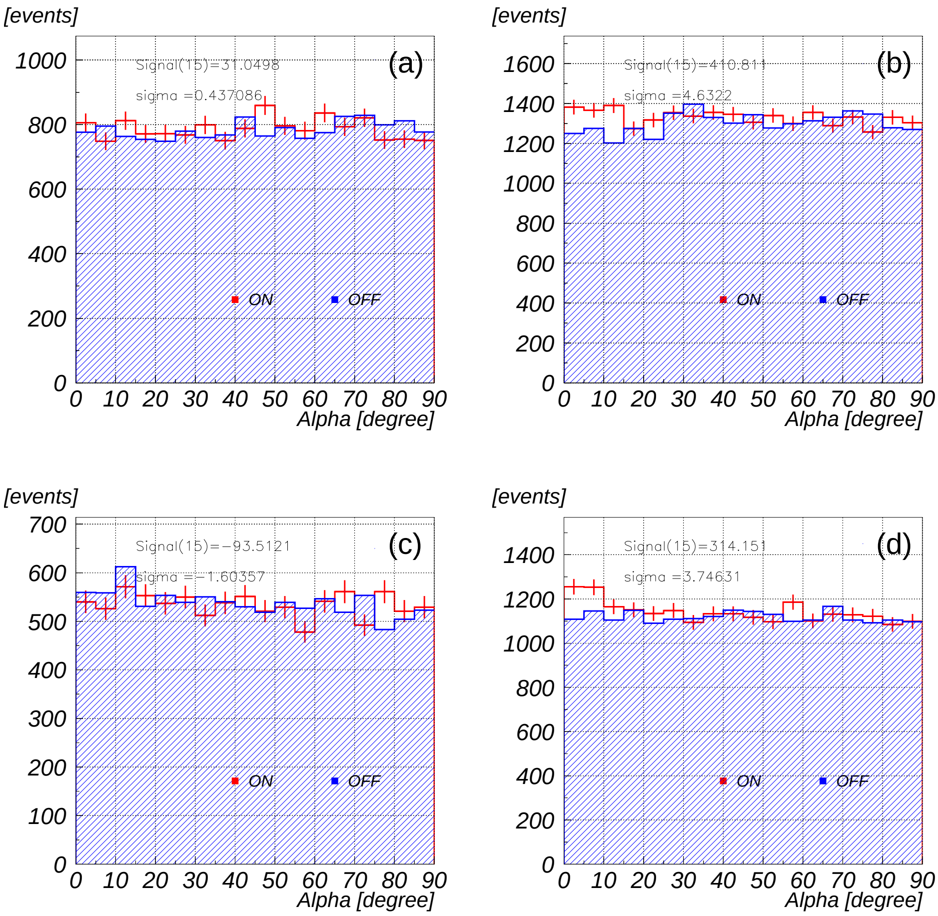

Fig. 3. Preliminary "Alpha" distribution for ON-source (solid line) and OFF-source (hatched histogram); (a) below ~1 TeV (2001), (b) above ~1 TeV (2001), (c) below ~1 TeV (2002), and (d) above~1 TeV (2002).